

Multi-Lepton Events at HERA

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The analysis of events containing multiple high P_T leptons (electrons and muons) produced in $e^\pm p$ collisions has been performed with the H1 and ZEUS detectors at HERA, using the full data sets collected by the experiments in the period 1994 – 2007. Mutually exclusive event topologies containing at least two charged leptons are analysed. The H1 and ZEUS data, corresponding to a total integrated luminosity of about 1 fb^{-1} , are combined in a common phase space. The observed event yields are compared to the predictions from the Standard Model. In general a good agreement is found, where the expectation is dominated by photon–photon collisions. Interesting events at high mass and high P_T are observed by both experiments. The total and differential cross sections for multi–lepton production at HERA are also measured.

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1. Introduction

At HERA, protons with an energy up to 920 GeV were brought into collision with electrons or positrons of energy 27.6 GeV at two experiments, H1 and ZEUS, each of which collected about 0.5 fb^{-1} of data in the period 1994–2007. The collisions produced at HERA at a centre of mass energy of up to 319 GeV provide an ideal environment to study rare processes, set constraints on the Standard Model (SM) and search for new particles and physics beyond the Standard Model (BSM). The good lepton identification and hadronic final state reconstruction of the H1 and ZEUS experiments means that such topologies provide a clean signal, and the high mass, high P_T regions, where the SM expectation is low, may be investigated for signs of new physics. Measurements of both multi-electron [1] and muon pair [2] production at high transverse momentum were performed by the H1 Collaboration using their HERA I data sample (1994–2000), which corresponds to an integrated luminosity of 115 pb^{-1} . Both H1 [3] and ZEUS [4] have now published analyses of multi-lepton events using their complete data sets. A combined analyses of the complete HERA data has also been performed [5].

2. Multi-lepton Events at HERA

The production of multi-lepton final states in $e^\pm p$ collisions proceeds in the SM mainly via photon-photon interactions. Multi-lepton events are simulated using the GRAPE [6] Monte Carlo (MC), which includes all electroweak matrix elements at tree level. The amount of SM background present in the analysis depends on the number and flavour of the identified leptons in the event. Neutral current deep inelastic scattering (NC DIS, $ep \rightarrow eX$) and QED Compton scattering (QEDC, $ep \rightarrow e\gamma X$) events contribute as background to multi-lepton events with at least one identified electron in the final state. The background contribution to the number of events with two identified muons or more than two identified leptons is negligible.

Electrons are identified in the polar-angle range $5^\circ < \theta_e < 175^\circ$ with $E_e > 10 \text{ GeV}$ in the range $5^\circ < \theta_e < 150^\circ$ and $E_e > 5 \text{ GeV}$ in the backward region ($150^\circ < \theta_e < 175^\circ$). In the H1 analysis [3], electrons with an energy $E_e > 5 \text{ GeV}$ are also allowed in the forward region ($5^\circ < \theta_e < 20^\circ$). Muon candidates are identified in the range $20^\circ < \theta_\mu < 160^\circ$ with $P_T^\mu > 2 \text{ GeV}$. All lepton candidates are required to be isolated with respect to each other, as well as other calorimeter deposits and tracks in the event, by a minimum distance of at least 0.5 units in the $\eta - \phi$ plane.

At least two central ($20^\circ < \theta < 150^\circ$) lepton candidates are required, one of which must have $P_T^\ell > 10 \text{ GeV}$ and the other $P_T^\ell > 5 \text{ GeV}$. Additional leptons identified in the detector according to the criteria defined above may be present in the event. According to the number and the flavour of the lepton candidates, the events are classified into mutually exclusive topologies, such as ee , eee , $e\mu$, $e\mu\mu$, $\mu\mu$ and so on. A full description of the event selection is presented in [5].

3. Results

In the H1 and ZEUS analyses the number of observed events in the various event topologies is found in general to be in good agreement with the SM prediction [3, 4]. The SM prediction is dominated by multi-lepton events, and only the ee topology contains significant SM background,

arising from NC DIS and QEDC processes. Interesting events are however observed by both H1 and ZEUS at high invariant mass M_{12} , which is constructed from the highest two P_T leptons in the event. Two such events are displayed in figure 1. Furthermore, in the H1 analysis five events are observed in the kinematic region $\sum P_T > 100$ GeV compared to a SM expectation of 1.60 ± 0.20 . All five events are observed in the e^+p data, compared to a SM expectation of 0.96 ± 0.12 .

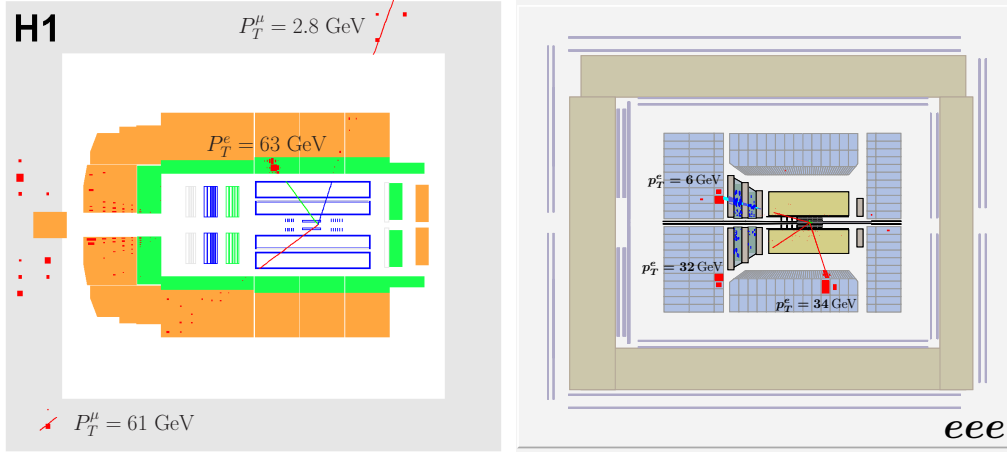


Figure 1: High mass events observed in the H1 (left) and ZEUS (right) multi-lepton analyses. In the H1 $e\mu\mu$ event, the invariant mass M_{12} of the electron and the highest P_T muon is 127 GeV. In the ZEUS eee event, the invariant mass M_{12} of the two highest P_T electrons is 113 GeV.

An analysis of the full HERA data sample, corresponding to an integrated luminosity of 0.94 fb^{-1} , is performed in a common phase space. The electron energy threshold is increased in the H1 analysis from 5 to 10 GeV in the forward region. Both the number of the observed events and the cross sections for multi-lepton production measured by the two experiments are combined, allowing an increased sensitivity to rare processes in the high mass and high P_T regions and an improved precision in the measured cross section. Once again, in general a good overall agreement is found between the data and the SM predictions. However, for $\sum P_T > 100$ GeV, seven events are observed in the data, compared to 3.13 ± 0.26 expected from the SM. In addition to the five events from H1 described above, two further data events are observed in this region by ZEUS. The combined $\sum P_T$ distributions for the full HERA data are shown in figure 2, separately for the e^+p and e^-p data. It can be seen that all of the high $\sum P_T$ events are recorded in the e^+p data, where seven events are observed compared to a SM expectation of 1.94 ± 0.17 .

The lepton-pair production cross section is measured in a phase space dominated by photon-photon interactions as $0.66 \pm 0.03(\text{stat.}) \pm 0.03(\text{sys.})$ pb, in agreement with the SM prediction of 0.69 ± 0.02 pb. The cross section is also measured as a function of the transverse momentum of the leading lepton, $P_T^{\ell_1}$ and the invariant mass of the lepton pair $M_{\ell\ell}$, as shown in figure 3.

4. Conclusions

The final analyses of multi-lepton events at HERA have been completed, including a combination of the full H1 and ZEUS data. In general a good agreement is observed between the data and the SM expectation. Events are observed by both H1 and ZEUS with high invariant mass of

the two highest transverse momentum leptons, $M_{12} > 100$ GeV, and a high scalar sum of the lepton transverse momenta, $\Sigma P_T > 100$ GeV, but only in the e^+p collision data. The total and differential cross sections for multi-lepton production at HERA are also measured.

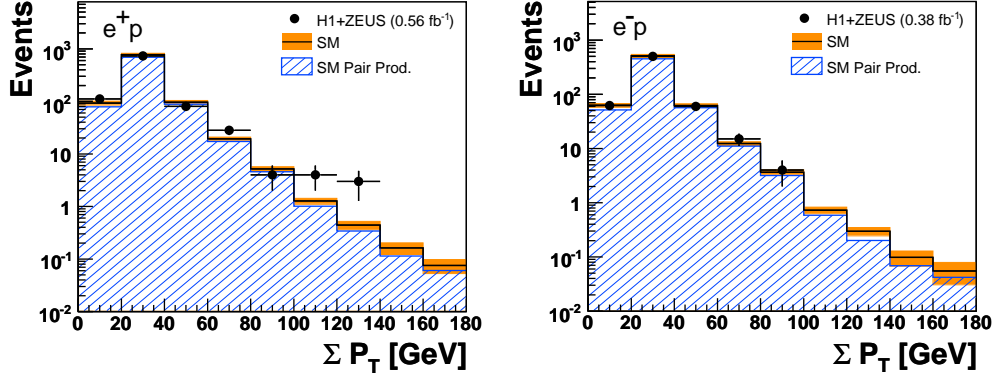


Figure 2: The distribution of the scalar sum of the transverse momenta ΣP_T for the combined di-lepton and tri-lepton events in the complete HERA e^+p (left) and e^-p (right) data. The points are the data and the full histogram is the total SM expectation, where the shaded band indicates the uncertainty on the SM prediction. The signal component of the SM expectation is shown by the striped histogram.

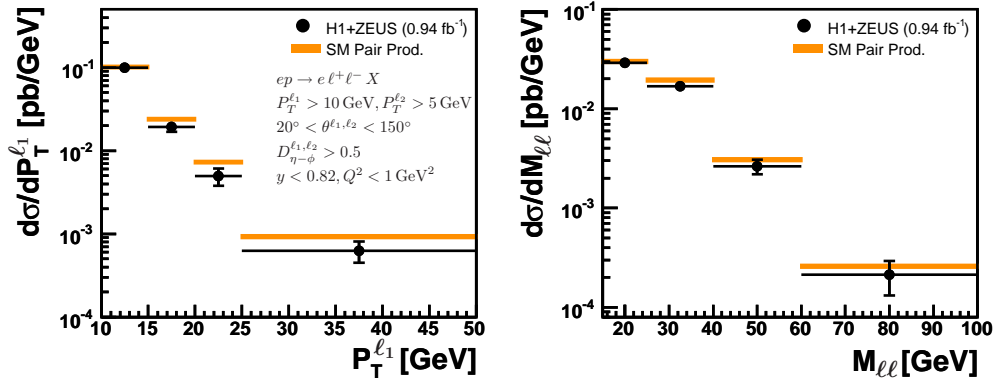


Figure 3: The cross section for lepton-pair photoproduction as a function of the leading lepton transverse momentum $P_T^{\ell_1}$ (left) and the invariant mass of the lepton pair $M_{\ell\ell}$ (right). The error on the data (points) represents the statistical and systematic uncertainties added in quadrature. The shaded band represents the uncertainty on the SM prediction.

References

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